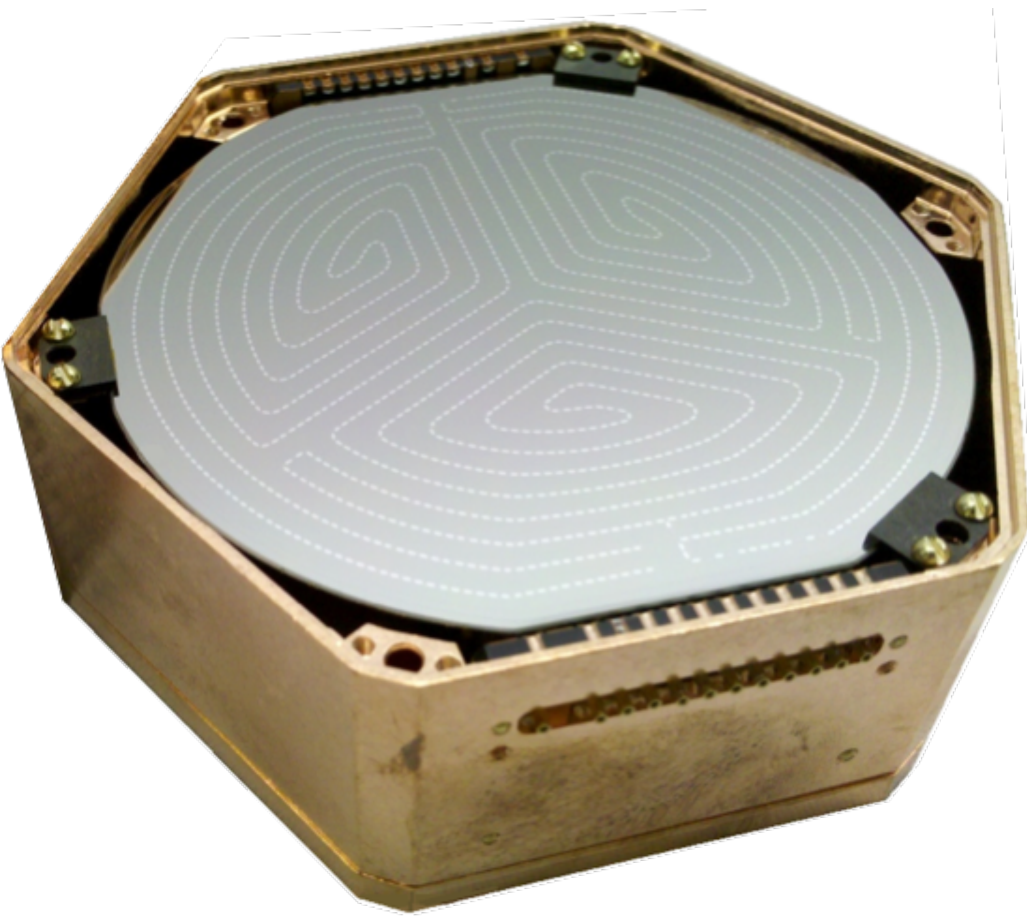
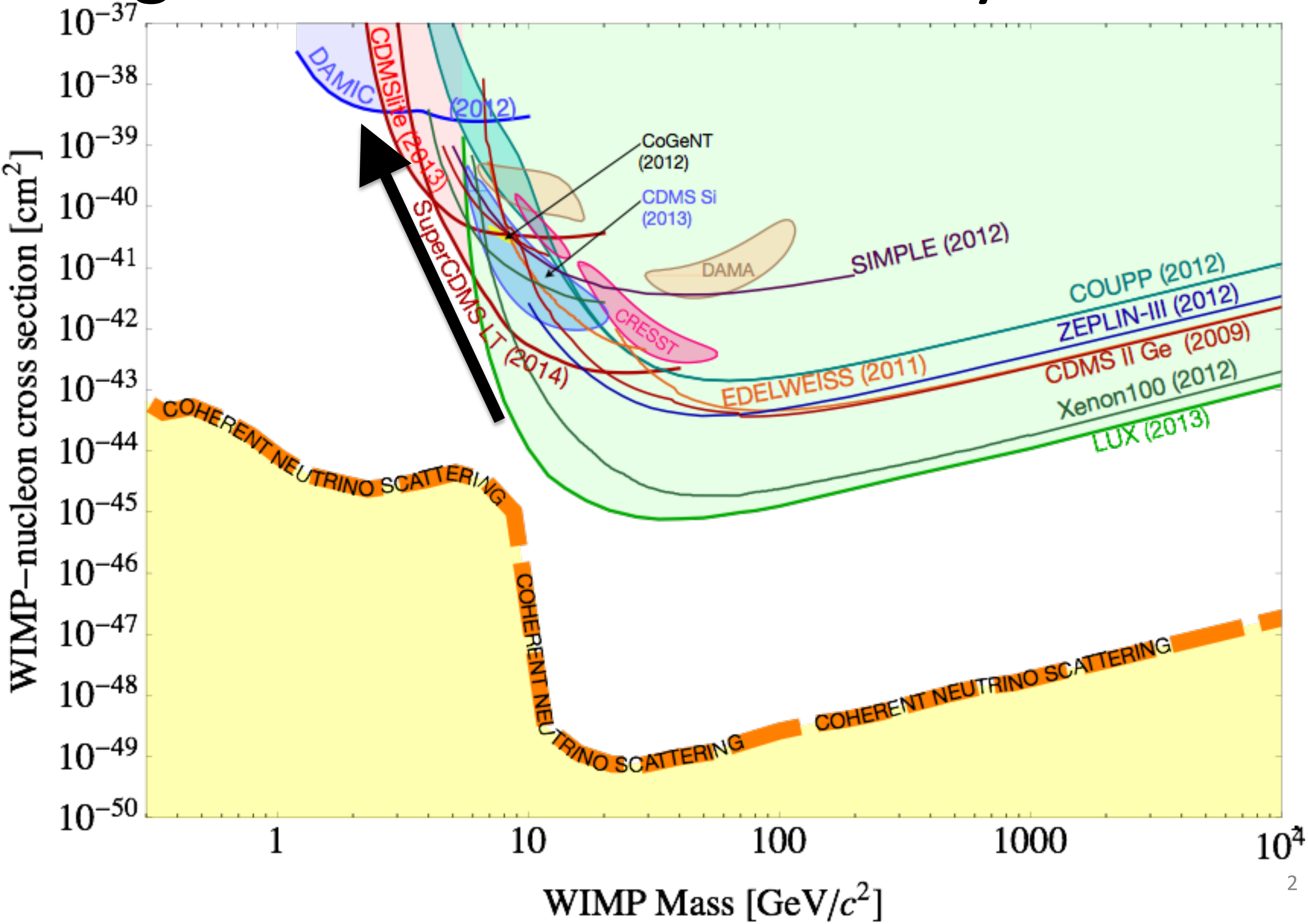
Improving the Energy Sensitivity of Massive Calorimeters to Search for Light Mass Dark Matter



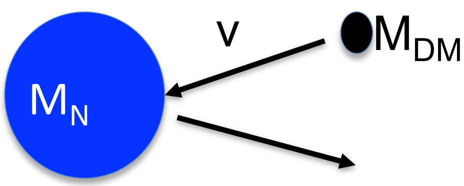
Matt Pyle
University of California Berkeley

LBL: Dark Matter Workshop
15/06/08

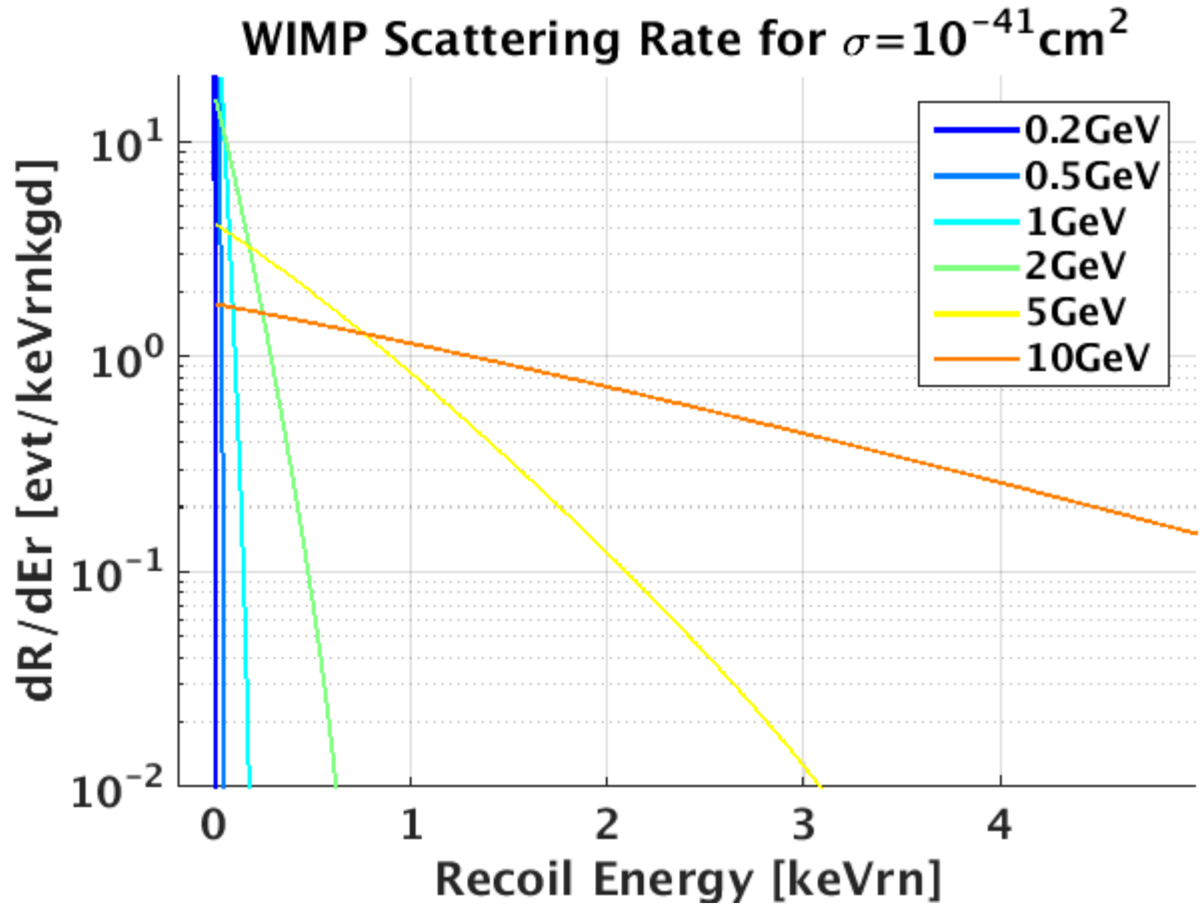
Light Mass DM Limits: Why So Bad?



The low-mass WIMP Direct Detection Challenge

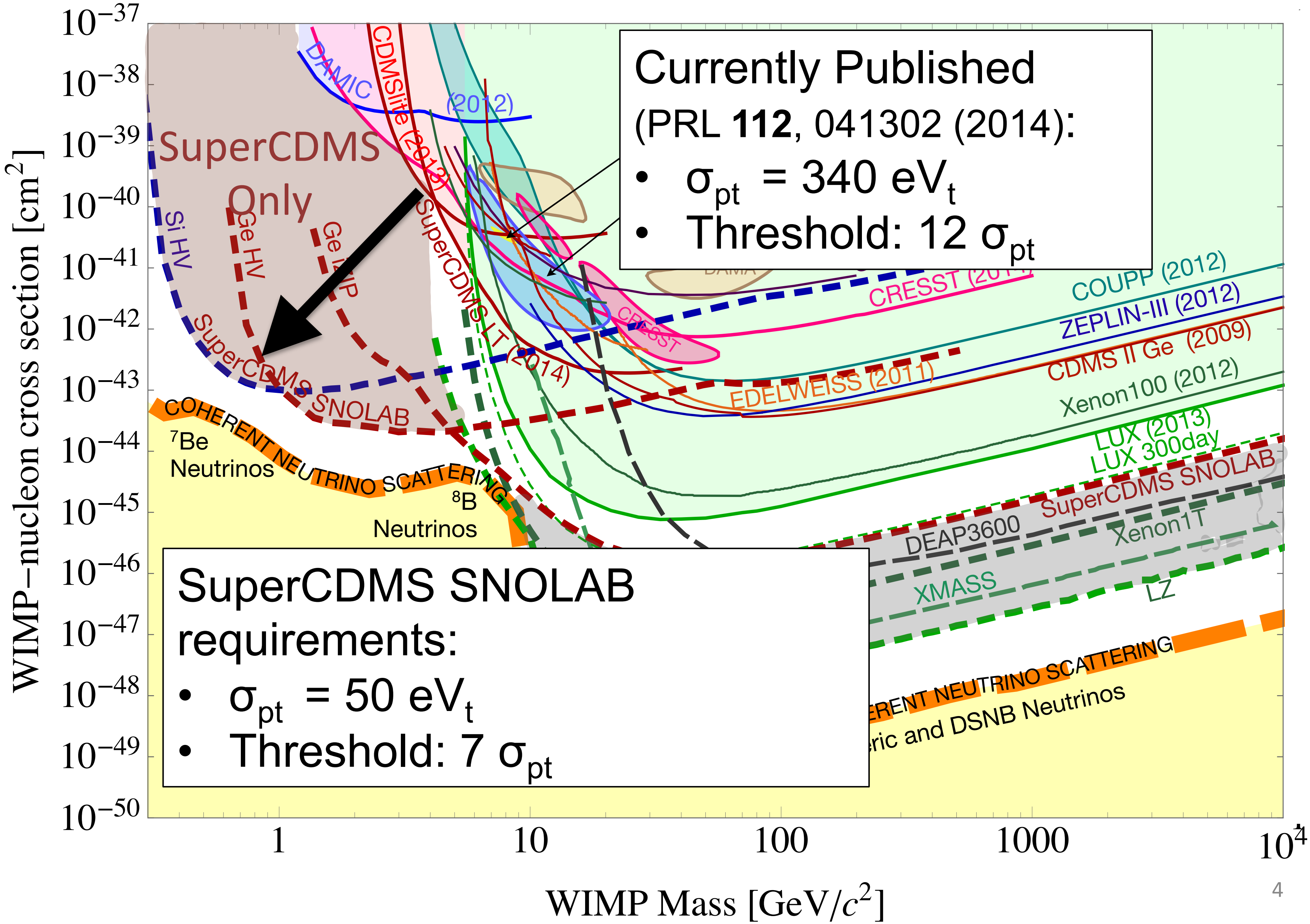


$$\Delta E = \frac{\Delta P^2}{2M_N} \sim \frac{2M_{DM}^2 v^2}{M_N}$$

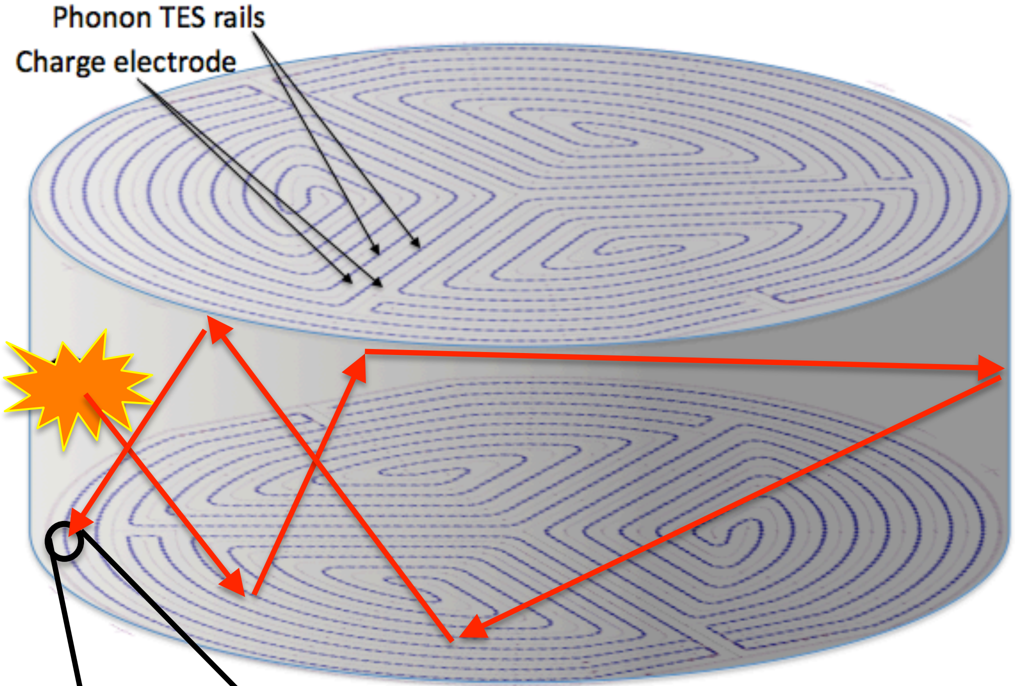


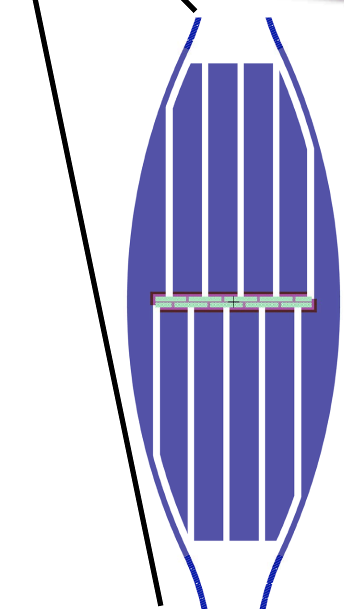
Detector Requirement: Amazing Energy Sensitivity

CDMSlite → SuperCDMS SNOLAB

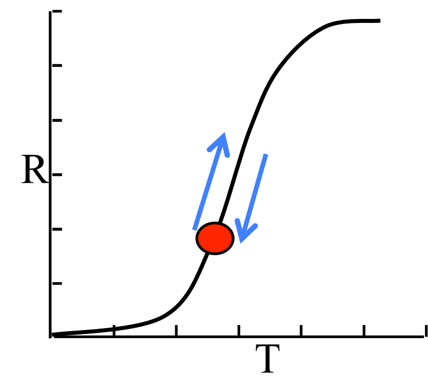


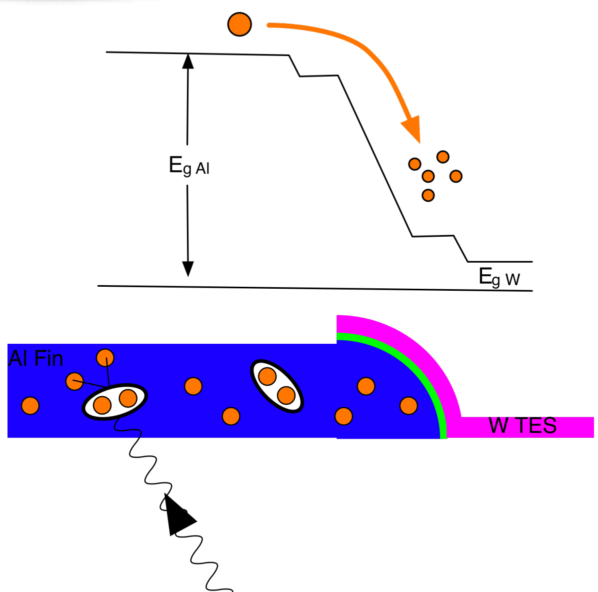
Athermal Phonon Sensors

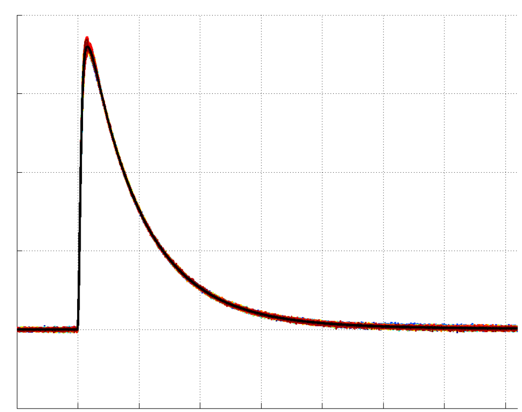




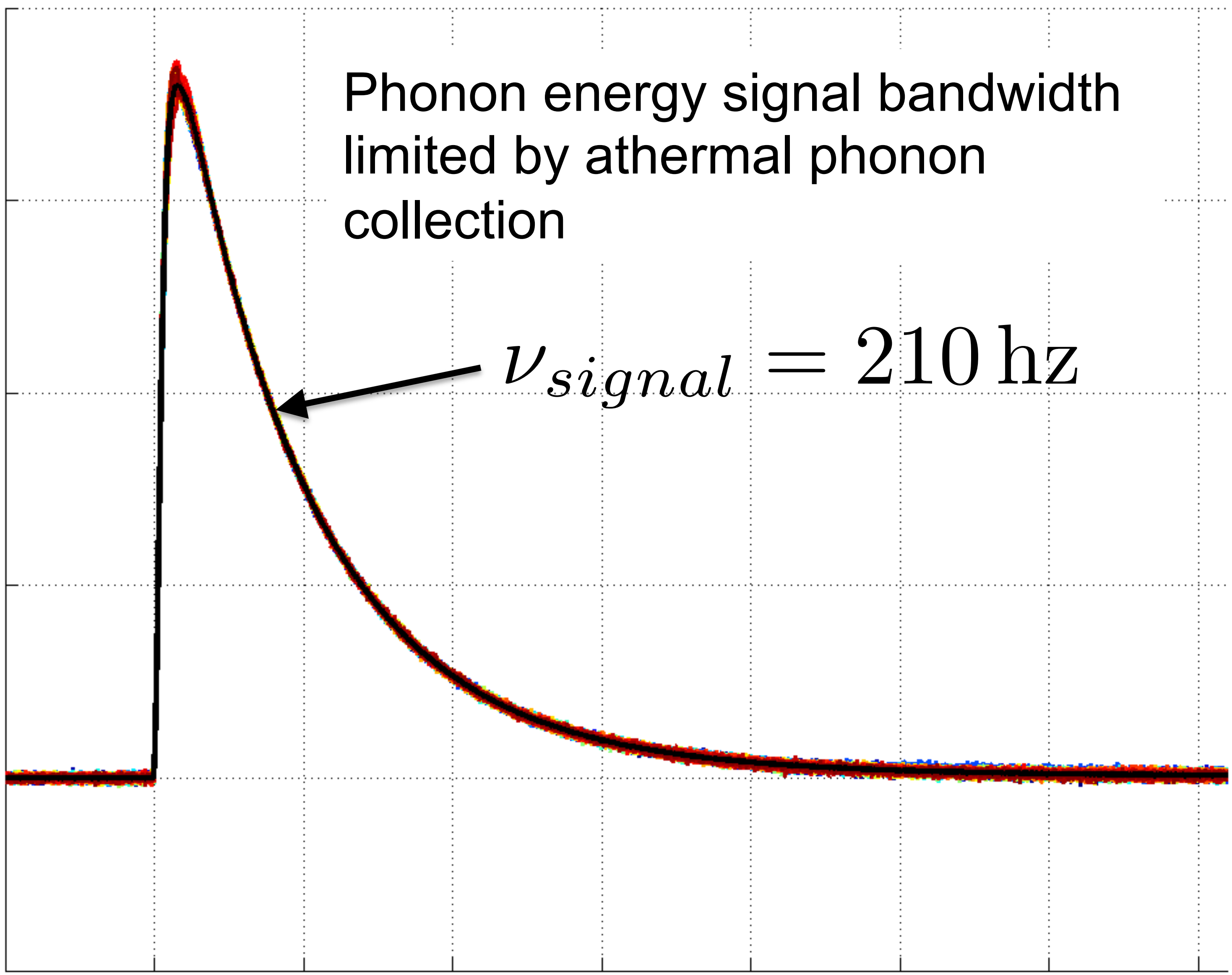
Collect and Concentrate Phonon Energy into W TES (Transition Edge Sensor)



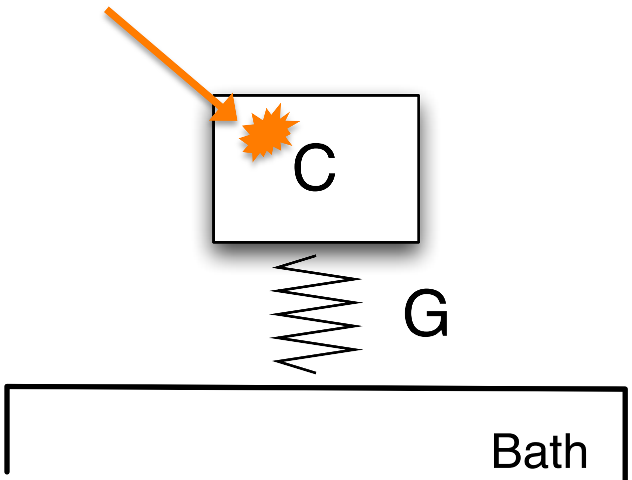


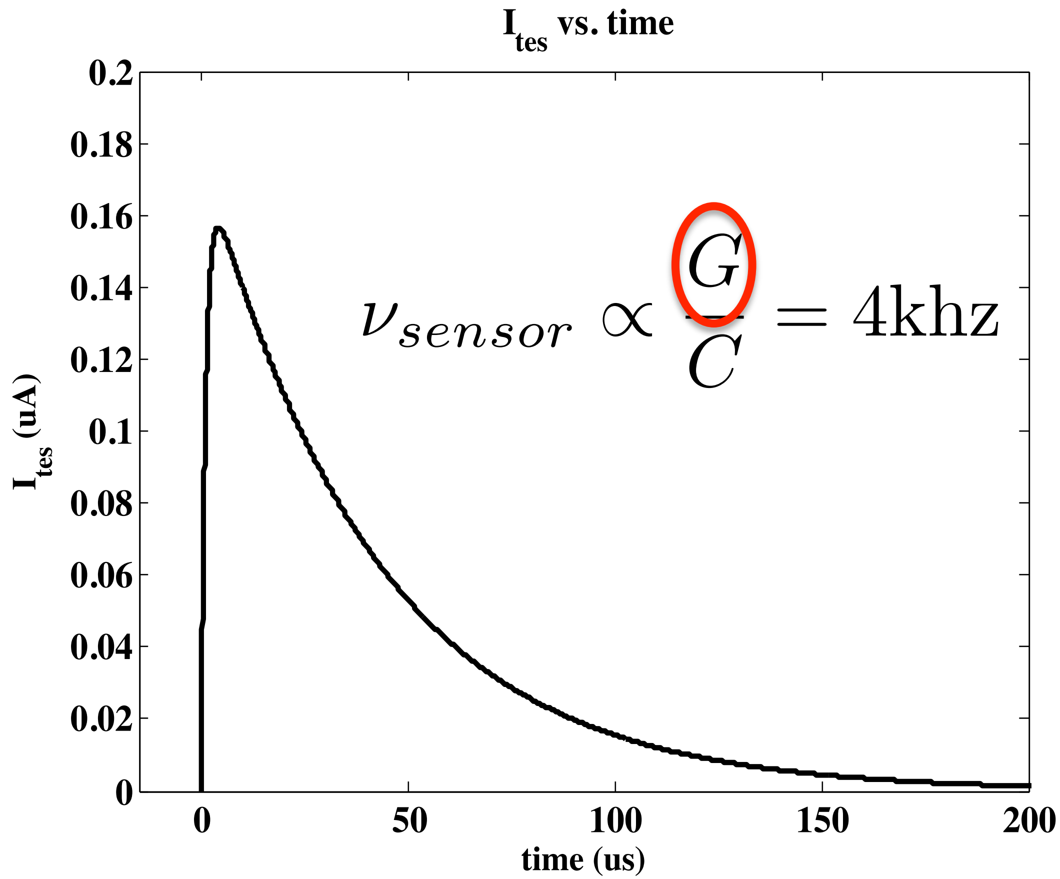


Phonon Signal Bandwidth



Transition Edge Sensor: Dynamics

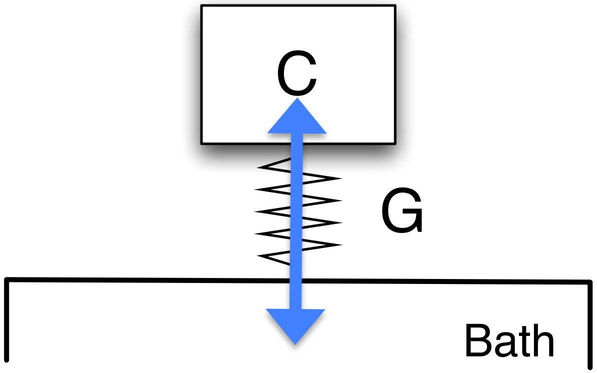




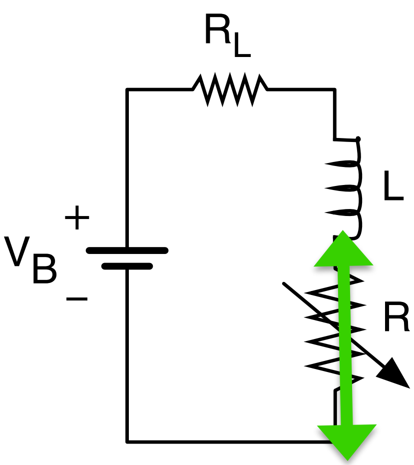
$$\nu_{sensor} \propto \frac{G}{C} = 4\text{khz}$$

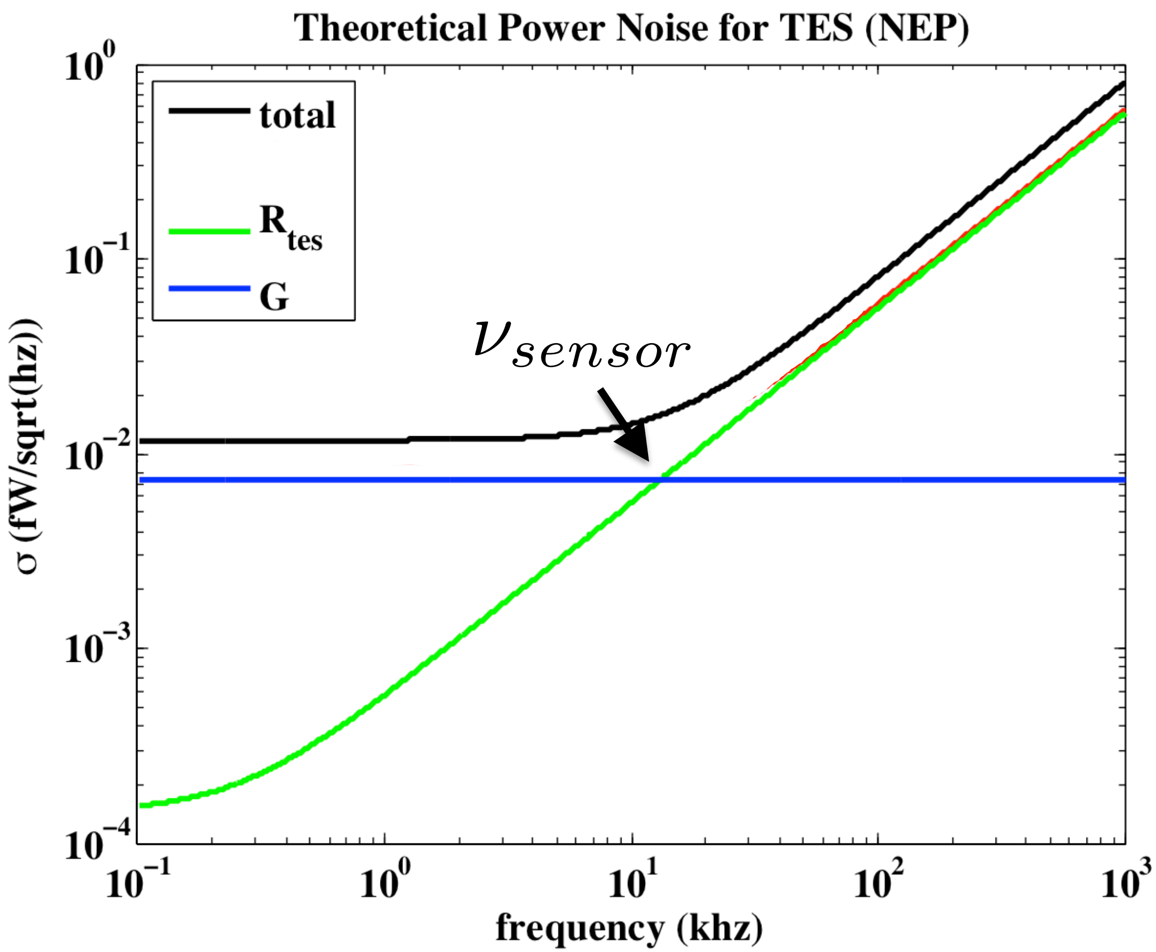
$$\nu_{signal} << \nu_{sensor}$$

Transition Edge Sensor: Noise



$S_{pG} = 4k_bT^2\mathbf{G}$

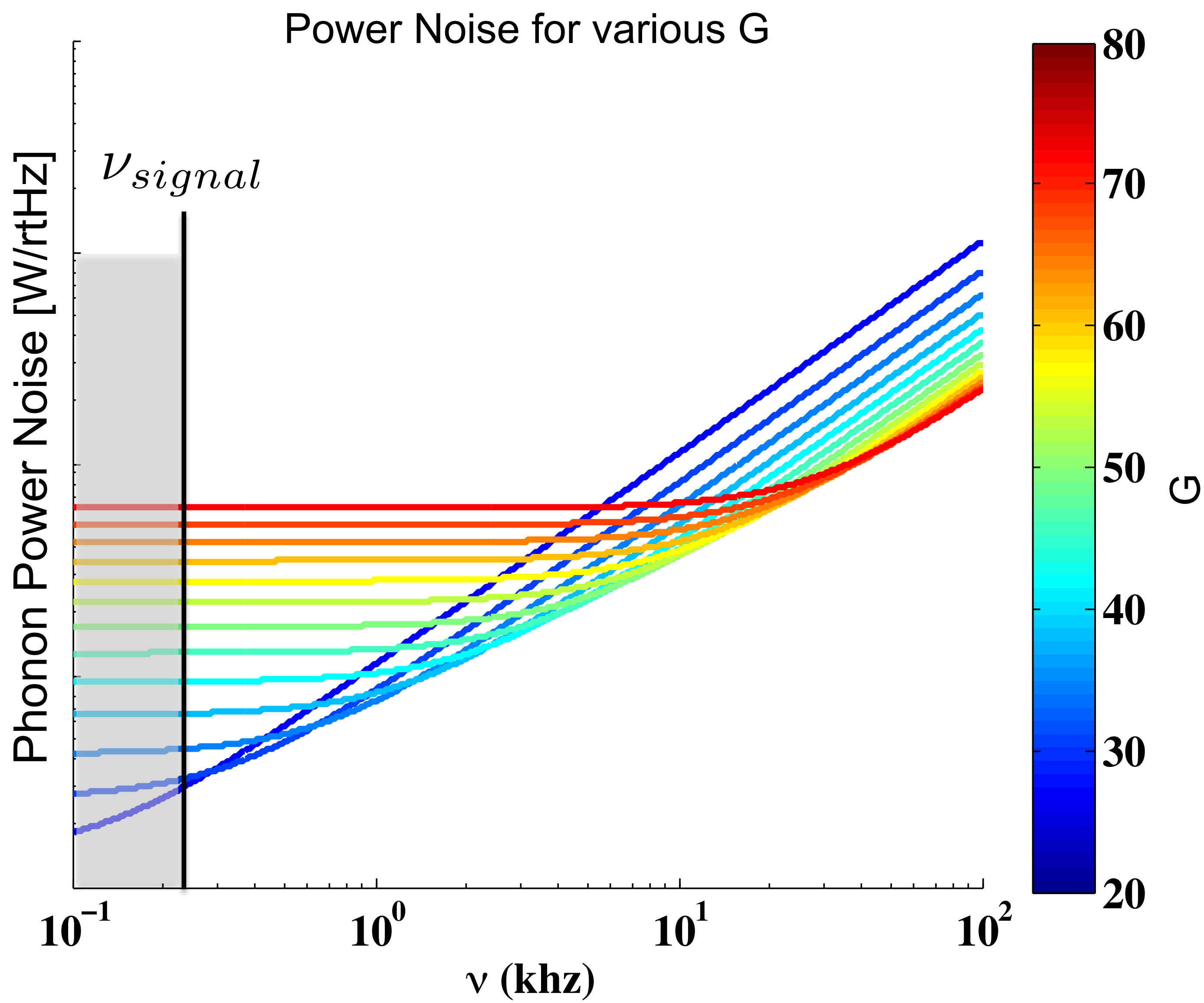




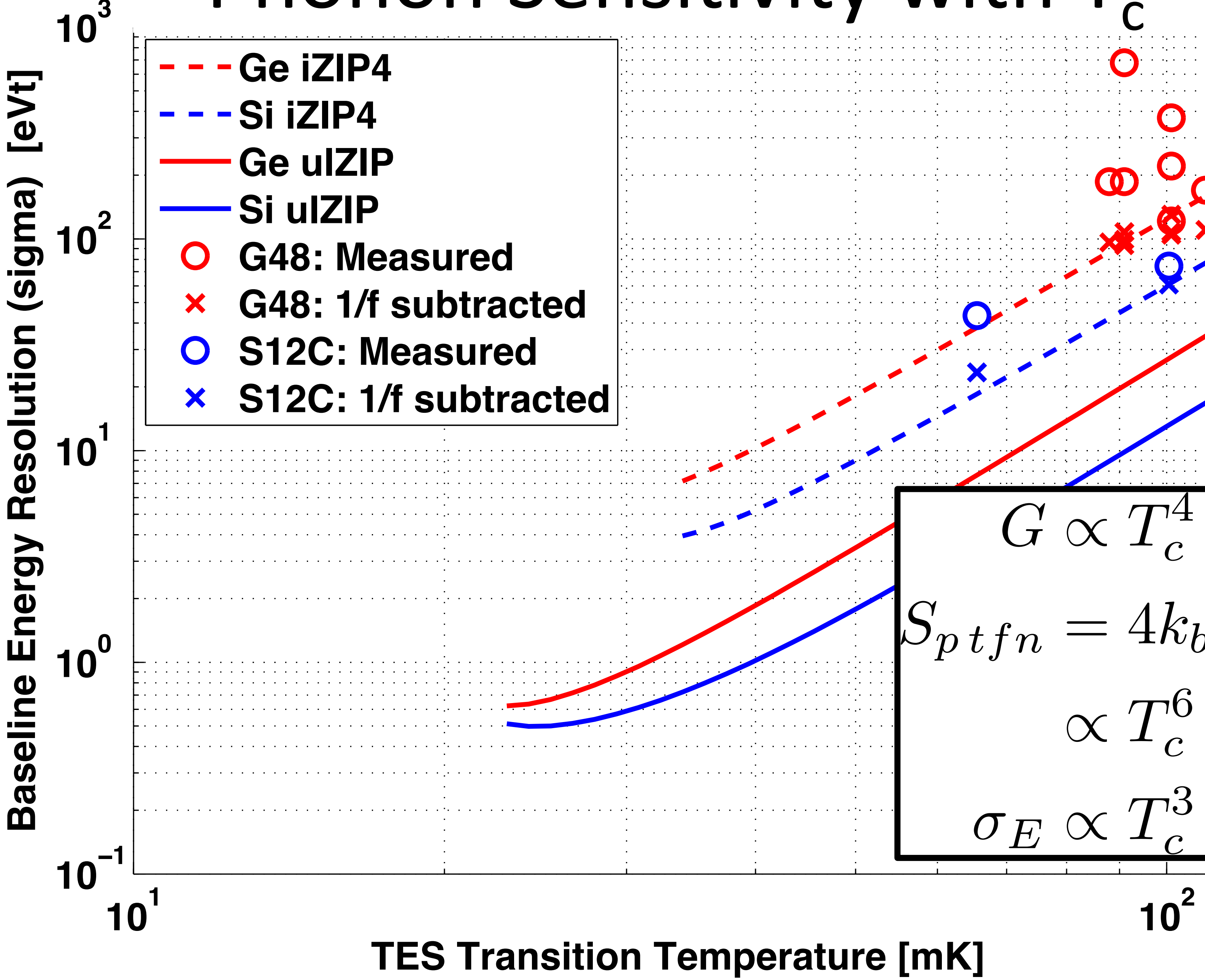
DC noise scales with G

Bandwidth Optimization Rule

$$\nu_{sensor} < \nu_{signal}$$

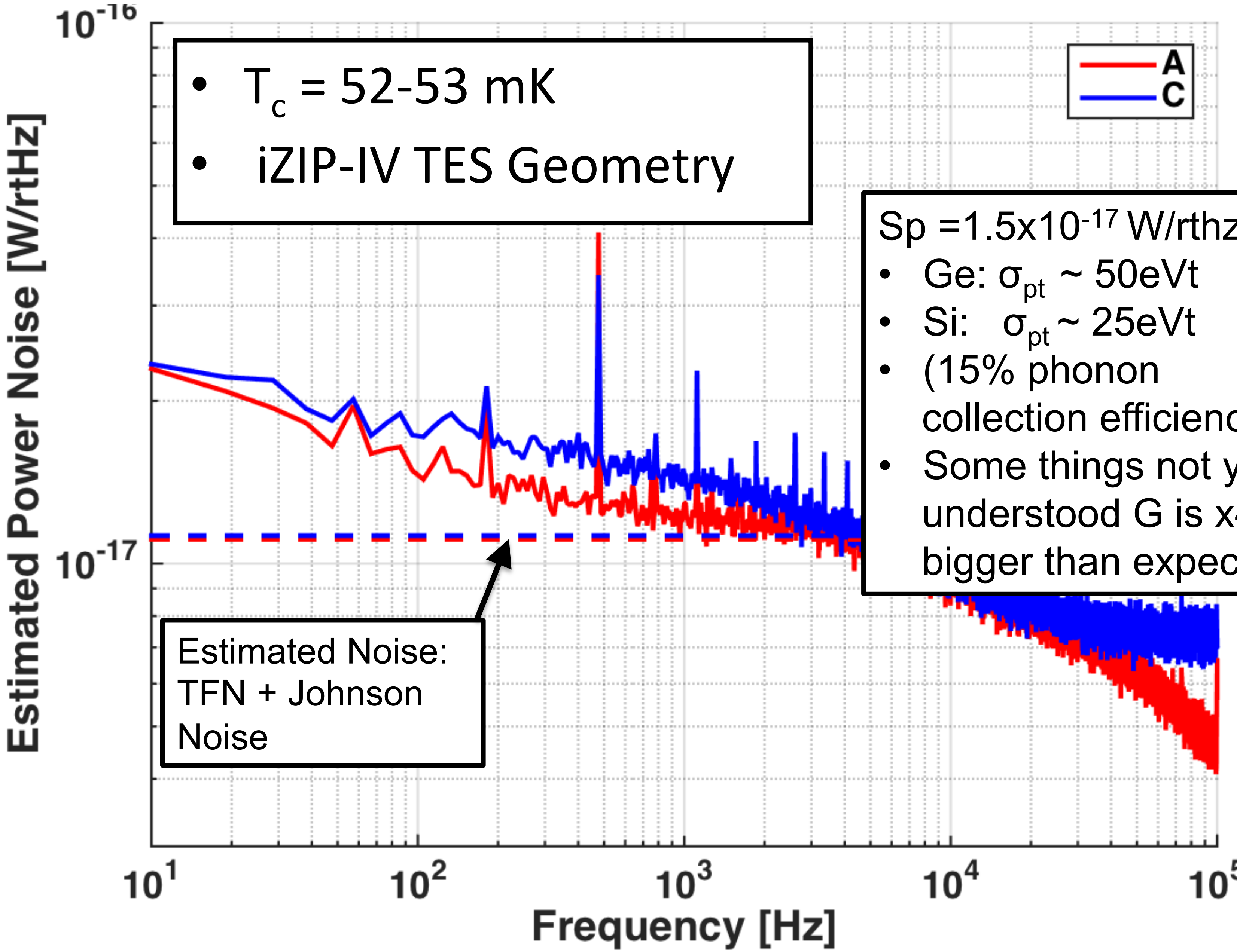


Phonon Sensitivity with T_c



$$G \propto T_c^4$$
$$S_{ptfn} = 4k_b T_c^2 G$$
$$\propto T_c^6$$
$$\sigma_E \propto T_c^3$$

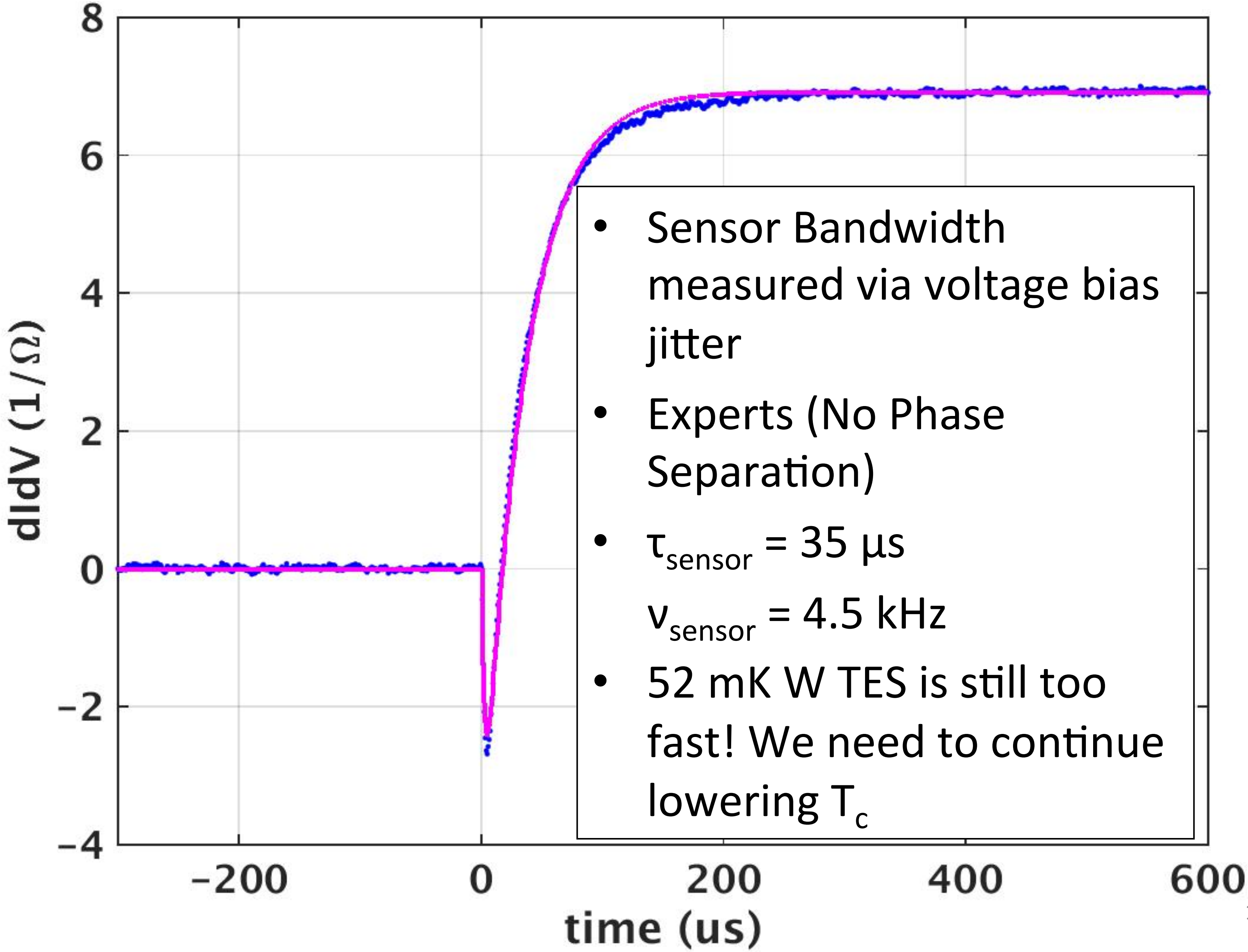
New: Noise of G23R Test Device



Sp =1.5x10^{-17} W/rthz:

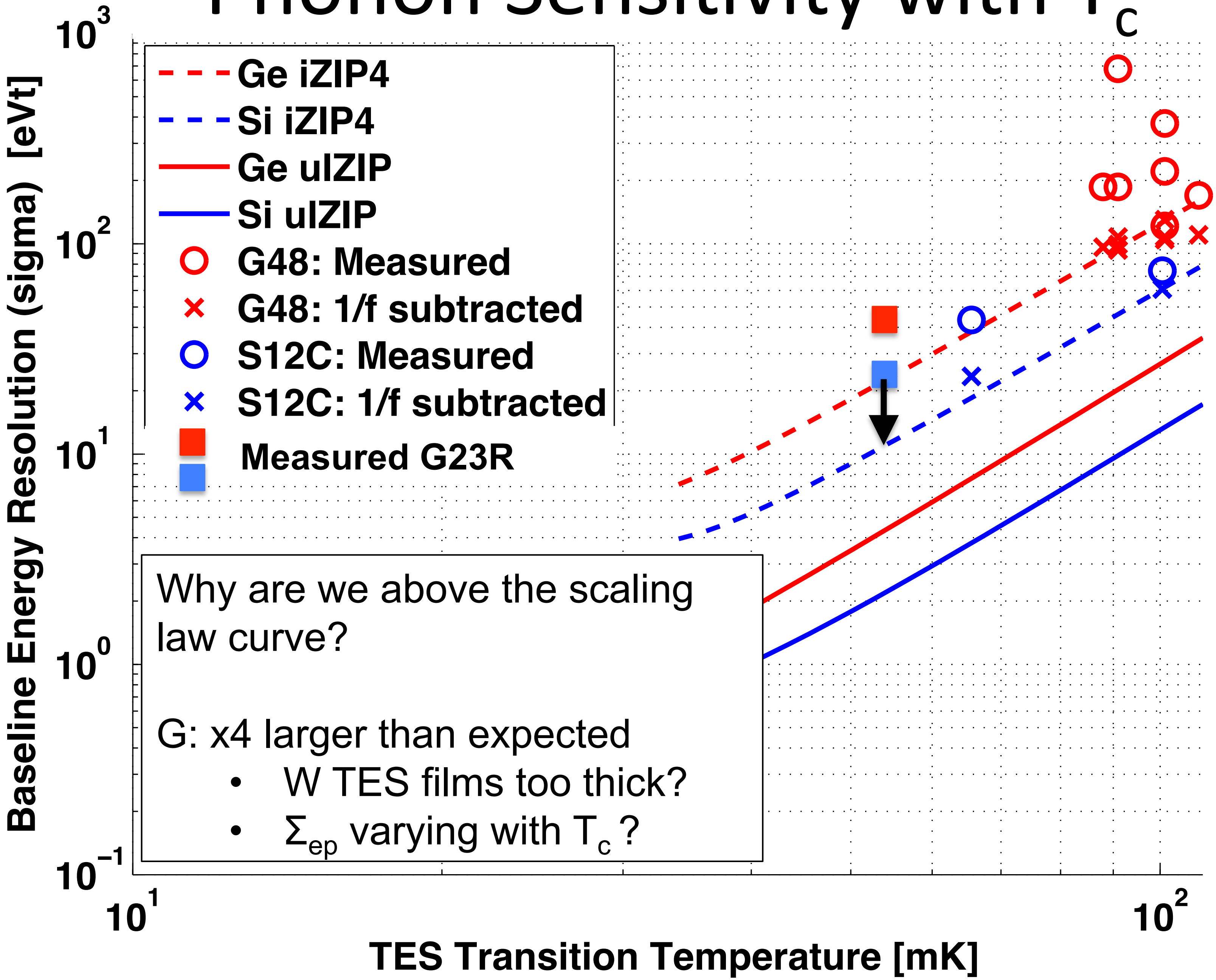
- Ge: σ_{pt} ~ 50eVt
- Si: σ_{pt} ~ 25eVt
- (15% phonon collection efficiency)
- Some things not yet understood G is x4 bigger than expected

New: G23R Sensor Bandwidth



- Sensor Bandwidth measured via voltage bias jitter
- Experts (No Phase Separation)
- τ_{sensor} = 35 μs
  ν_{sensor} = 4.5 kHz
- 52 mK W TES is still too fast! We need to continue lowering T_c

Phonon Sensitivity with T_c



Why are we above the scaling law curve?

G: x4 larger than expected

- W TES films too thick?
- Σ_{ep} varying with T_c?

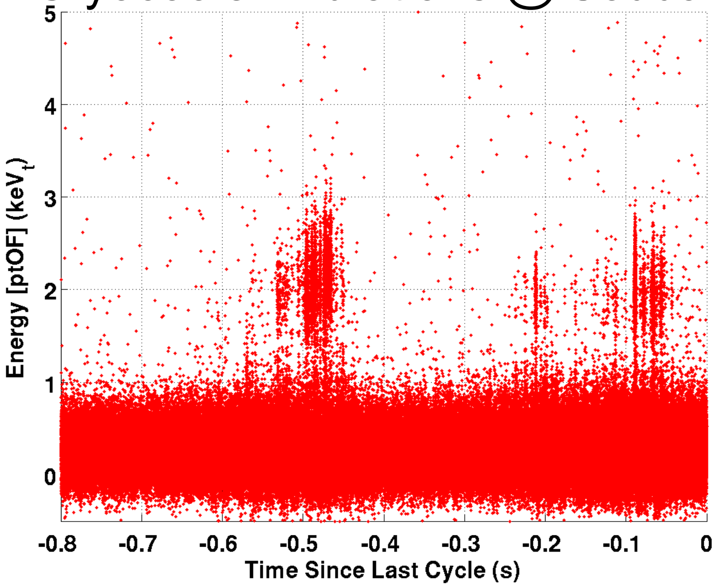
Why is it taking so long?

What are the fundamental limits in phonon resolution?

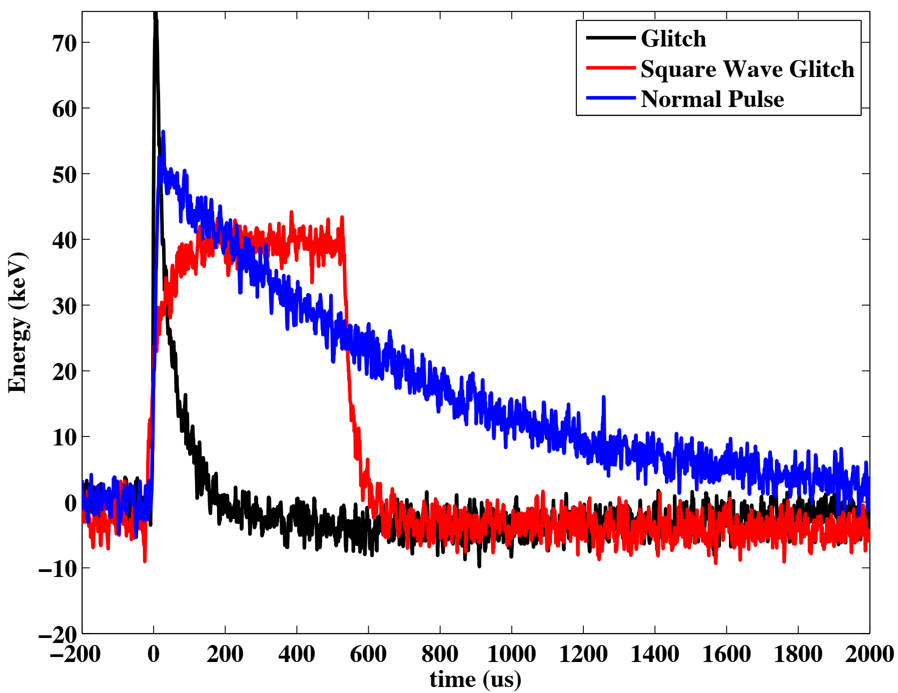
Problem #1: Parasitic Power

As we lower $T_{c,}$ we become more sensitive to nuclear recoils, but we also become more sensitive to environmental noise

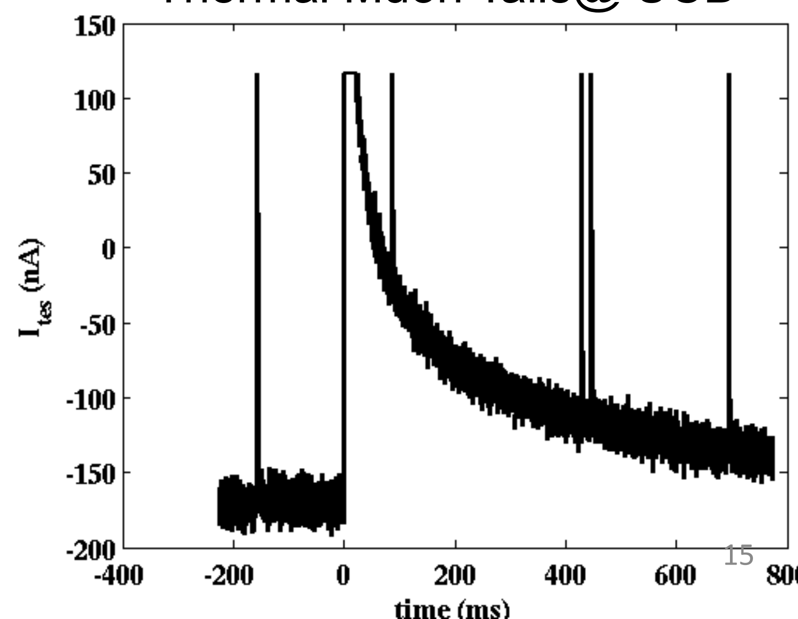
Cryocooler Vibrations @ Soudan



EMI Interference @ UCB

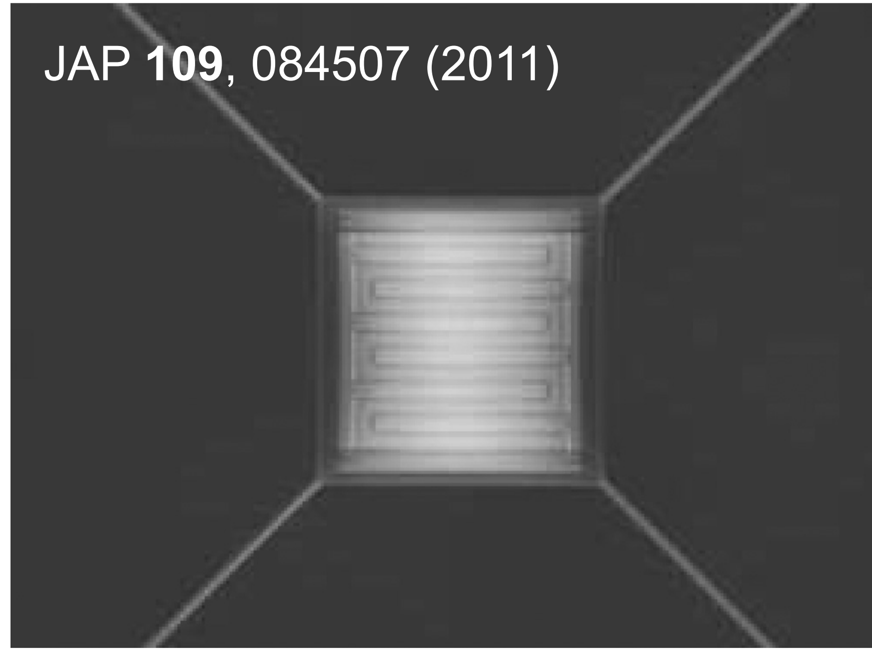


Thermal Muon Tails@ UCB



Resolution Limits: Parasitic Power

SAFARI has created devices with x75 smaller G & x9 smaller P_{bias} than we require

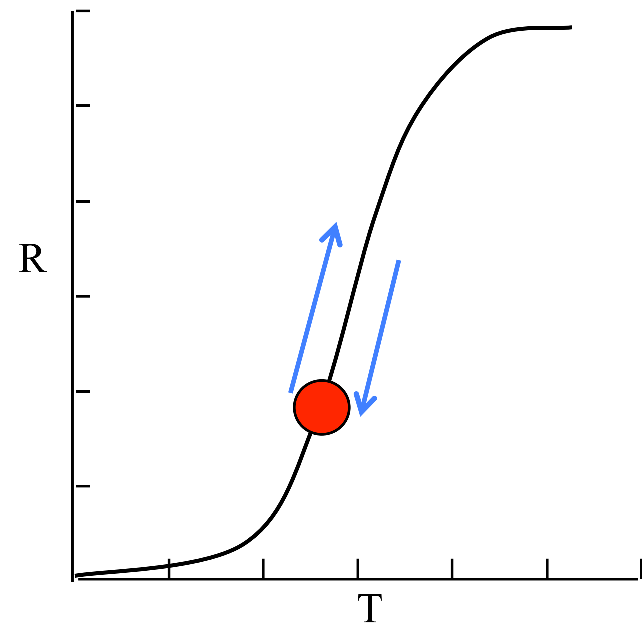


	SuperCDMS (modeled)	SAFARI (measured)
Tc	30 mK	111 mK
G	12800 fW/K	170 fW/K
P_{bias}	76 fW	8.9 fW
S_{NEP}	6×10^{-19} W/rthz	4.2×10^{-19} W/rthz

We're far from the fundamental limits on phonon resolution due to parasitic power

Problem #2: W TES Sensitivity Degradation at low T_c?

- As we continue to lower T_c, does the W TES lose sensitivity? Does it become impossible to fabricate?
- Who knows?
- 100mK -> 50mK sensitivity remained invariant
- If yes, there are lots of other TES material out there

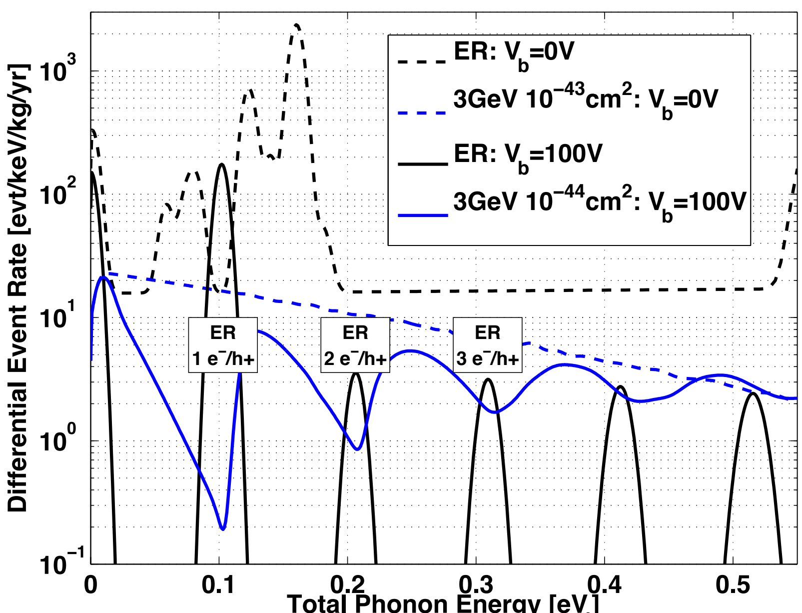


Problem #3: Base Temperature

- Dilution Fridge base temperature < ~70% T_c
- Short Term: Definitely an issue for SuperCDMS
  - UCB 75uW: 35 mK
- Long Term: Shouldn't be a problem
  - New DF at UCB/SLAC/Northwestern/FNAL (10mK)
  - Queen's DF: 7mK
  - SNOLAB: Designing for hopefully 15mK

Summary

- We're slowly, but surely, continuing to improve our phonon energy resolution by lowering T_c and improving our environmental shielding.
- Currently at σ_{pt} ~ $50eV_t$ (Ge)/$25eV_t$ (Si). We have met requirements for SuperCDMS using 75mm detectors, but not yet with a larger 100mm detector.
- Over the coming 5 years we hope to really explore the limits of the technology (ER/NR rejection via charge quantization)



Backup

Option 2: (n^0,γ)

PHYSICAL REVIEW A VOLUME 11, NUMBER 4 APRIL 1975

Energy lost to ionization by 254-eV ^{73}Ge atoms stopping in Ge†

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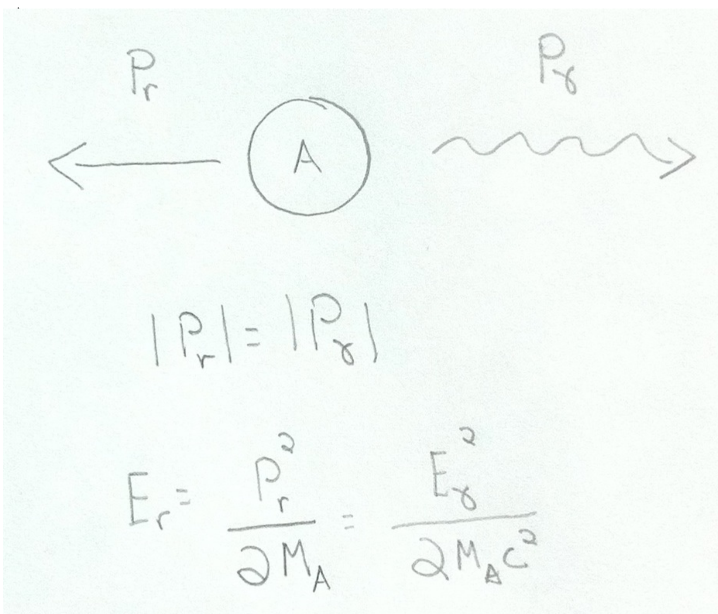
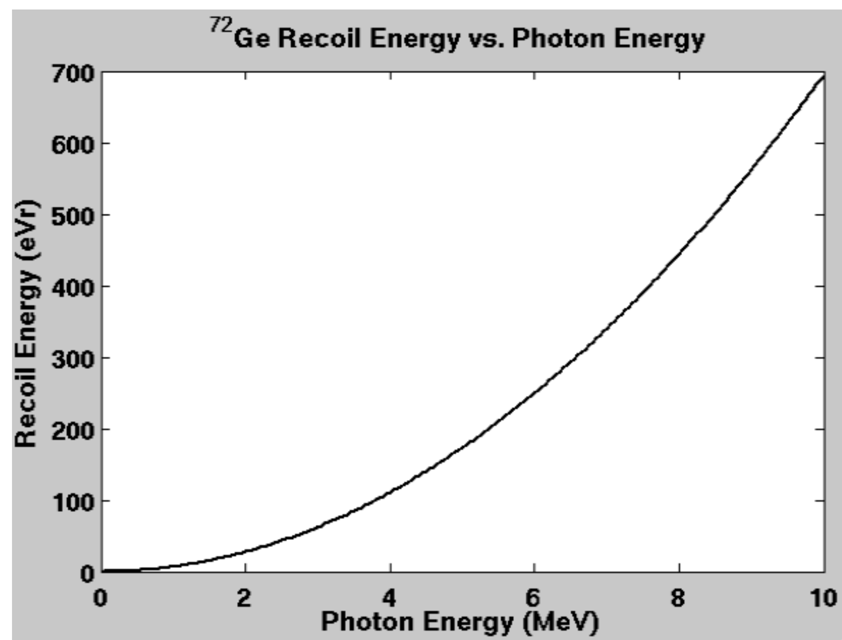
(Received 30 July 1974)

A 1-cm^3 Ge(Li) γ-ray detector was placed directly in a beam of thermal neutrons where the ^{72}Ge$(n,\gamma)^{73}$Ge reaction produced 254-eV ^{73}Ge recoil atoms in the detector. The primary capture γ rays from the reaction were detected in a 7.6-cm × 7.6-cm NaI(Tl) detector placed at 90° to the incident beam. In addition to singles measurements a coincidence between the primary capture γ ray and the γ ray or conversion electrons from the decay of the 68.75-keV ^{73}Ge third excited state was used to search for directional effects in the stopping and to check the value of the recoil energy deduced from the feeding of the 68.75-keV level. The level energy was remeasured and a value of 68.755 ± 0.005 keV was found, which when combined with the results of previous work gives a value of 68.7535 ± 0.0043 keV. The amount of energy lost to ionization in the stopping of the 254-eV ^{73}Ge atom is found from the energy shift in the peak position for the 68.75-keV level. Our measurement of this shift gives a value of 39.2 ± 5.5 eV, which is then the energy loss to ionization by the stopping of the 254-eV ^{73}Ge recoil atom. This result is (27 ± 3)% higher than the theoretical estimate made from an extrapolation of the Lindhard theory to this energy region. An attempt to observe a dependence of the ionization loss on the recoil direction in the Ge crystal was made, but no positive effect was observed.

- Brought to us by Juan
- Photon needs to be huge!





Ge Yield and Lindhard